UNITED STATES PATENT APPLICATION FOR:

MULTIPORT POLISHING FLUID DELIVERY SYSTEM

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MULTIPORT POLISHING FLUID DELIVERY SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] Embodiments of the invention generally relate to a method and apparatus for polishing a substrate in a chemical mechanical polishing system.

Description of the Related Art

[0002] In semiconductor wafer processing, the use of chemical mechanical planarization, or CMP, has gained favor due to the enhanced ability to increase device density on a semiconductor workpiece, or substrate, such as a wafer. Chemical mechanical planarization systems generally utilize a polishing head to retain and press a substrate against a polishing surface of a polishing material while providing motion therebetween. Some planarization systems utilize a polishing head that is moveable over a stationary platen that supports the polishing material. Other systems utilize different configurations to provide relative motion between the polishing material and the substrate, for example, providing a rotating platen. A polishing fluid is typically disposed between the substrate and the polishing material during polishing to provide chemical activity that assists in the removal of material from the substrate. Some polishing fluids may also contain abrasives.

[0003] One of the challenges in developing robust polishing systems and processes is providing uniform material removal across the polished surface of the substrate. For example, as the substrate travels across the polishing surface, the edge of the substrate is often polished at a higher rate. This is due in part to the tendency of the substrate to "nose drive" due to frictional forces as the substrate moves across the polishing surface.

[0004] Another problem affecting polishing uniformity across the substrate's surface is the tendency of some materials to be removed faster than the

surrounding materials. For example, copper is generally removed more rapidly than the material surrounding the copper material (typically an oxide) during polishing. The faster removal of copper, often referred to a dishing, is particularly evident when the width of the copper surface exceeds five microns.

[0005] Although many solutions have been utilized in order to mitigate the non-uniformity of the substrate as a result of polishing, none have proved to be completely satisfactory. Thus, the demand for uniform, highly planarized surfaces is still a paramount concern due to the trend toward smaller decreased line sizes and increased device density.

[0006] Therefore, there is a need for improved polishing uniformity in chemical mechanical planarization systems.

SUMMARY OF THE INVENTION

[0007] In one aspect of the invention, a system for delivering a polishing fluid to a chemical mechanical polishing surface is provided. In one embodiment, the system includes an arm having a delivery portion disposed at least partially over the polishing surface. A first nozzle and a second nozzle are disposed on the delivery portion of the arm. The first nozzle is adapted to flow the polishing fluid at a first rate while the second nozzle is adapted to flow the polishing fluid at a second rate that is different than the first rate.

[0008] In another aspect of the invention, a method for delivering a polishing fluid to a chemical mechanical polishing surface is provided. In one embodiment, the method includes the steps of supplying polishing fluid to one location of a chemical mechanical polishing surface at a first rate and providing polishing fluid to a second location of the polishing surface at a second rate which is different than the first rate.

DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present invention are attained and can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference

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to the embodiments thereof which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0010] Fig. 1 is a simplified schematic of a polishing system having one embodiment of a polishing fluid delivery system;

[0011] Fig. 2 is a plan view of the system of Fig. 1;

[0012] Fig. 3 depicts a simplified schematic of another polishing fluid delivery system; and

[0013] Fig. 4 is a comparison of polishing uniformity on substrates polished on conventional polishing system and the system of Fig. 1.

[0014] To facilitate understanding, identical reference numerals have been used, wherever possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0015] Fig. 1 depicts one embodiment of a polishing system 100 for polishing a substrate 112 having a polishing fluid delivery system 102 that controls the distribution of polishing fluid 114 across a polishing material 108. Examples of polishing systems which may be adapted to benefit from aspects of the invention are disclosed in United States Patent Application No. 09/144,456, filed February 4, 1999 by Birang, et al. and United States Patent No. 5,738,574, issued April 14, 1998 to Tolles, et al., both of which are hereby incorporated by reference in their entirety. Although the polishing fluid delivery system 102 is described in reference to the illustrative polishing system 100, the invention has utility in other polishing systems that process substrates in the presence of a polishing fluid.

[0016] Generally, the exemplary polishing system 100 includes a platen 104 and a polishing head 106. The platen 104 is generally positioned below the polishing head 106 that holds the substrate 112 during polishing. The platen 104 is generally disposed on a base 122 of the system 100 and coupled to a motor

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(not shown). The motor rotates the platen 104 to provide at least a portion of a relative polishing motion between the polishing material 108 disposed on the platen 104 and the substrate 112. It is understood that relative motion between the substrate 112 and the polishing material 108 may be provided in other manners. For example, at least a portion of the relative motion between the substrate 112 and polishing material 108 may be provided by moving the polishing head 106 over a stationary platen 104, moving the polishing material linearly under the substrate 112, moving both the polishing material 108 and the polishing head 106 and the like.

[0017] The polishing material 108 is generally supported by the platen 104 so that a polishing surface 116 faces upward towards the polishing head 106. Typically, the polishing material 108 is fixed to the platen 104 by adhesives, vacuums, mechanical clamping or the like during processing. Optionally, and particularly in applications where the polishing material 108 is configured as a web, the polishing material 108 is releasably fixed to the platen 104, typically by use of a vacuum disposed between the polishing material 108 and platen 104 as described in the previously incorporated United States Patent Application No. 09/144,456.

[0018] The polishing material 108 may be a conventional or a fixed abrasive material. Conventional polishing material 108 is generally comprised of a foamed polymer and disposed on the platen 104 as a pad. In one embodiment, the conventional polishing material 108 is a foamed polyurethane. Such conventional polishing material 108 is available from Rodel Corporation, located in Newark, Delaware.

[0019] Fixed abrasive polishing material 108 is generally comprised of a plurality of abrasive particles suspended in a resin binder that is disposed in discrete elements on a backing sheet. Fixed abrasive polishing material 108 may be utilized in either pad or web form. As the abrasive particles are contained in the polishing material itself, systems utilizing fixed abrasive polishing materials generally utilize polishing fluids that do not contain abrasives. Examples of fix abrasive polishing material are disclosed in United States Patent

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No. 5,692,950, issued December 2, 1997 to Rutherford et al., and United States Patent No. 5,453,312, issued September 26, 1995 to Haas et al, both of which are hereby incorporated by reference in their entireties. Such fixed abrasive material 108 is additionally available from Minnesota Manufacturing and Mining Company (3M), located in Saint Paul, Minnesota.

[0020] The polishing head 106 generally is supported above the platen 104. The polishing head 106 retains the substrate 112 in a recess 120 that faces the polishing surface 116. The polishing head 106 typically moves toward the platen 104 and presses the substrate 112 against the polishing material 108 during processing. The polishing head 106 may be stationary or rotate, isolate, move orbitally, linearly or a combination of motions while pressing the substrate 112 against the polishing material 108. One example of a polishing head 106 that may be adapted to benefit from the invention is described in United States Patent No. 6,183,354 B1, issued February 6, 2001 to Zuniga et al., and is hereby incorporated by reference in its entirety. Another example of a polishing head 106 that may be adapted to benefit from the invention is a TITAN HEAD™ wafer carrier, available from Applied Materials, Inc., of Santa Clara, California.

[0021] The polishing fluid delivery system 102 generally comprises a delivery arm 130, a plurality of nozzles 132 disposed on the arm 130 and at least one polishing fluid source 134. The delivery arm 130 is configured to meter polishing fluid 114 at different flow rates along the arm 130 to control the distribution of polishing fluid 114 on the polishing surface 116 of the polishing material 108. As the polishing fluid 114 is generally supplied from a single source, the polishing fluid 114 is disposed on the polishing material 108 in a uniform concentration but in varying amounts along the width (or diameter) of the polishing material 108.

[0022] The delivery arm 130 is generally coupled to the base 122 proximate the platen 104. The delivery arm 130 generally has at least a portion 136 that is suspended over the polishing material 108. The delivery arm 130 may be coupled to other portions of the system 100 as long as the portion 136 is positionable to deliver polishing fluid 114 to the polishing surface 116.

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[0023] The plurality of nozzles 132 are disposed along the portion 136 of the delivery arm 130 which is disposed above the platen 104. In one embodiment, the nozzles 132 comprise at least a first nozzle 140 and a second nozzle 142. Typically, the first nozzle 140 is positioned on the arm 130 radially inward of the second nozzle 142 relative to the center of rotation of the polishing material 108. The distribution of polishing fluid 114 across the polishing material 108 is controlled by flowing polishing fluid 114 from the first nozzle 140 at a rate different than the flow from the second nozzle 142.

[0024] As depicted in Fig. 2, the first nozzle 140 generally flows polishing fluid 114 at a first rate to a first portion 202 of the polishing surface 116 while the second nozzle 142 flows polishing fluid 114 at a second rate to a second portion 104 of the polishing surface 116. In this manner, the distribution of polishing fluid 114 across the width of the polishing material 108 is regulated.

[0025] Returning to Fig. 1, the flow rates exiting the first and second nozzles 140, 142 are generally different from one another. The flow rates may be fixed relative to each other or controllable. In one embodiment, the fluid delivery arm 130 includes a polishing fluid supply line 124 that is teed between the first and second nozzles 140, 142. A tee fitting 126 is coupled to the supply line 124 and has a first delivery line 144 and a second delivery line 146 branching therefrom that are coupled respectively to the nozzles 140, 142.

[0026] At least one of the nozzles 132 contains a flow control mechanism 150. The flow control mechanism 150 may be a device which provides a fixed ratio of flow between the nozzles 140, 142 or the flow control mechanism 150 may be adjustable to provide dynamic control of the flow rates. Examples of flow control mechanisms 150 include fixed orifices, pinch valves, proportional valves, restrictors, needle valves, restrictors, metering pumps, mass flow controllers and the like. Alternatively, the flow control mechanism 150 may be provided by a difference in the relative pressure drop between the fluid delivery lines 144, 146 coupling each nozzle 140, 142 and the tee fitting 126.

[0027] The polishing fluid source 134 is typically disposed externally to the system 100. In one embodiment, the polishing fluid source 134 generally

includes a reservoir 152 and a pump 154. The pump 154 generally pumps the polishing fluid 114 from the reservoir 152 through the supply line 124 to the nozzles 132.

[0028] The polishing fluid 114 contained in the reservoir 152 is typically de-ionized water having chemical additives that provide chemical activity that assists in the removal of material from the surface of the substrate 112 being polished. As the polishing fluid 114 is supplied to the nozzles 132 from a single source (*i.e.,* the reservoir 152), the fluid 114 flowing from the nozzles 132 is substantially homogeneous, *i.e.,* not varied in concentration of chemical reagents or entrained abrasives. Optionally, the polishing fluid may include abrasives to assist in the mechanical removal of material from the surface of the substrate. The polishing fluids are generally available from a number of commercial sources such as Cabot Corporation of Aurora, Illinois, Rodel Inc., of Newark, Delaware, Hitachi Chemical Company, of Japan, Dupont Corporation of Wilmington, Delaware among others.

[0029] In operation, the substrate 112 is positioned in polishing head 106 and brought in contact with the polishing material 108 supported by the rotating platen 104. The polishing head 106 may hold the substrate stationary, or may rotate or otherwise move the substrate to augment the relative motion between the polishing material 108 and substrate 112. The polishing fluid delivery system 102 flows the polishing fluid 114 through the supply line 124 to the first and second polishing nozzles 140, 142.

[0030] Fig. 2 depicts a plan view of the system 100 illustrating the flow of polishing fluid 114 onto the portions 202 and 204 of the polishing material 108. A first flow 206 of polishing fluid 114 flows out the first nozzle 140 and onto the first portion 202 at a first rate while a second flow 208 of polishing fluid 114 flows out the second nozzle 142 and onto the second portion 204 at a second rate. Generally, the first flow 206 is different than the second flow 208 thus providing a controlled distribution of polishing fluid 114 across the polishing surface 116 of the polishing material 108. In one embodiment, the first flow 206 has a rate that is at least about 1.15 times a rate of the second flow 208. The controlled

distribution of the polishing fluid 114 across the polishing material 108 allows material removal from the surface of the substrate 112 to be tailored across the width of the substrate 112 by controlling the relative flows of polishing fluid 114 onto the polishing material 108. Referring to Fig. 2 for example, more polishing fluid 114 may be provided to the first portion 202 of the polishing material 108 than the second portion 204 (or vice versa). Optionally, additional nozzles may be utilized to provide different amounts of polishing fluid 114 on other portions of the polishing material 108 where at least two portions of the polishing material 108 have polishing fluid 114 disposed thereon at different flow rates.

[0031] In one mode of operation for example, the substrate 112 being polished by the system 100 is processed with polishing fluid 114 provided from the first nozzle 140 and the second nozzle 142. Polishing fluid 114 is disposed on the polishing material 108 from the first nozzle 140 at a first rate. Polishing fluid 114 is simultaneously disposed on the polishing material 108 from the second nozzle 142 at a second rate. In one embodiment, the first flow is about 1.2 to about 20.0 times second flow rate. The resulting polishing uniformity 402 from the process utilizing the polishing fluid delivery system 102 is depicted in Fig. 4. Uniformity 404 of a conventional substrate polish achieved utilizing a conventional polishing fluid delivery system (*i.e.*, systems where polishing fluid is delivered to the polishing material solely from a single nozzle or tube) having the same total polishing fluid flow is provided for comparison. As illustrated in Fig. 4, the uniformity 402 is improved over conventional results 404.

[0032] In configurations having dynamic (*i.e.*, adjustable) control mechanisms 150 such as proportional valves, needle valves, mass flow controllers, metering pumps, peristaltic pumps and the like, the distribution of polishing fluid 114 on the polishing material 108 may be tailored during the process. For example, the rate of polishing fluid from the first nozzle 140 may be applied to the polishing material 108 at a first rate during one portion of the process and adjusted to a second rate during another portion of the process. The rate of polishing fluid 114 delivery from the second nozzle 142 may also be varied during the polishing process. It should be noted that the adjustments of

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polishing fluid flows from either nozzle 140, 142 are infinite. The use of additional nozzles disposed between the first nozzle 140 and the second nozzle 142 allows the uniformity profile to be further modified and locally shaped by providing more or less polishing fluid 114 at a nozzle disposed between the first nozzle140 and the second nozzle 142 (see discussion of Fig. 3 below).

[0033] Optionally, a polishing fluid delivery system having dynamic control over the flow rates from the nozzles 140, 142 may include a metrology device 118 to provide process feed-back for real-time adjustment of the polishing fluid distribution. Typically, the metrology device 118 detects a polishing metric such as time of polish, thickness of the surface film being polished on the substrate, surface topography or other substrate attribute.

[0034] In one embodiment, the polishing material 108 may include a window 160 that allows the metrology device 118 to view the surface of the substrate 112 disposed against the polishing material 108. The metrology device 118 generally includes a sensor 162 that emits a beam 164 that passes through the window 160 to the substrate 112. A first portion of the beam 164 is reflected by the surface of the substrate 108 while a second portion of the beam 164 is reflected by a layer of material underlying the polished surface of the substrate 108. The reflected beams are received by the sensor 162 and a difference in wavelength between the two portions of reflected beams are resolved to determine the thickness of the material on the surface of the substrate 112. Generally, the thickness information is provided to a controller (not show) that adjusts the polishing fluid distribution on the polishing material 108 to produce a desired polishing result on the substrate's surface. One monitoring system that may be used to advantage is described in United States Patent Application Serial No. 08/689,930, filed August 16, 1996 by Birang et al., and is hereby incorporated herein by reference in its entirety.

[0035] Optionally, the metrology device 118 may include additional sensors to monitor polishing parameters across the width of the substrate 112. The additional sensors allow for the distribution of polishing fluid 114 to be adjusted across the width of the substrate 112 so that more or less material is removed in

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one portion relative another portion of the substrate 112. Additionally, the process of adjusting the flow rates from the nozzles 140, 142 may occur iteratively over the course of a polishing sequence to dynamically control the rate of material removal across the substrate 112 at any time. For example, the center of the substrate 112 may be polished faster by providing more polishing fluid to the center of the substrate 112 at the beginning of a polishing sequence while the perimeter of the substrate 112 may be polished faster at the end of the polishing sequence by providing more polishing fluid to the perimeter area.

[0036] Fig. 3 depicts another embodiment of a polishing fluid delivery system 300 having a plurality of nozzles 302. The system 300 may be configured similarly to the fluid delivery system 102 of Fig. 1 (*i.e.,* having a single polishing fluid delivery line) or may be configure so that each nozzle 302 has a dedicated supply line 304 coupled to a fluid source 306. Fluidly coupled to each supply line 304 is a metering device 308. The metering device 308 may be a metering pump such as a gear pump, a peristaltic pump, a positive displacement pump, a diaphragm pump and the like. Each metering device 308 is coupled to a controller (not shown) that controls the amount of polishing fluid 114 provided to each nozzle 302 of the system 300. As each metering device 308 is independently controllable, the flow of polishing fluid 114 from each of the plurality of nozzles 302 is controlled independent from the other nozzles so that the distribution of polishing fluid 114 on the polishing material 108 can be arranged in practically infinite configurations.

[0037] As described above, each metering device may vary the flow of polishing delivered to the polishing material 108 over the course of polishing. For example, one of the nozzles 302 may increase the flow of polishing fluid 114 flowing therethrough while the substrate is being polished. Another one of the nozzles may decrease the flow of polishing fluid 114 during polishing. Of course, infinite variations in nozzle flow rates at any time may be configured to produce a desired polishing result. As the flow of polishing fluid is independently controllable through each nozzle 302, polishing attributes may be tailored across the width of the substrate over the duration of substrate processing.

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[0038] The fluid delivery source 306 may be used in concert with a metrology device 308 to control the rate or location of material removal from a surface 318 of the substrate 112 being polished. Generally, the rate of removal or remaining thickness of material disposed on the surface 318 of the substrate 112 may be detected by the metrology device 308 and provided to the controller which in turn, adjusts the various flow rates exiting each nozzle 302 to produce a desired polishing result, for example, faster polishing on the perimeter of the substrate 112.

[0039] In one embodiment, the polishing material 108 may include a window 310 that allows the metrology device 308 to view the surface 318 of the substrate 112 disposed against the polishing material 108. The metrology device 308 generally includes a sensor 314 that emits a beam 316 that passes through the window 310 to the substrate 112. A first portion of the beam 316 is reflected by the surface 318 of the substrate 108 while a second portion of the beam 316 is reflected by a layer 320 of material underlying the polished surface 318 of the substrate 108. The reflected beam is received by the sensor 314 and a difference in wavelength between the two portions of reflected beam is resolved to determine the thickness of the material on the surface 318 of the substrate 112. Generally, the thickness information is provided to the controller that adjusts the polishing fluid distribution on the polishing material 108 to produce a desired polishing result on the substrate's surface 318.

[0040] Optionally, the metrology device 308 may include additional sensors to monitor polishing parameters across the width of the substrate 112. The additional sensors allow for the distribution of polishing fluid 114 to be adjusted across the width of the substrate 112 so that more or less material is removed in one portion relative another portion of the substrate 112. Additionally, the process of adjusting the flow rates from the nozzles 302 may occur iteratively over the course of a polishing sequence to dynamically control the rate of material removal across the substrate 112 at any time. For example, the center of the substrate 112 may be polished faster by providing more polishing fluid to the center of the substrate 112 at the beginning of a polishing sequence while the

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perimeter of the substrate 112 may be polished faster at the end of the polishing sequence by providing more polishing fluid to the perimeter area.

[0041] Although the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise other varied embodiments that still incorporate the teachings and do not depart from the scope and spirit of the invention.